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Use of Fire Streams to Control Floating Oil

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USE OF FIRE STREAMS TO CONTROL FLOATING OIL

by

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Project 15080 FVP

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ABSTRACT

The substantial momentum output of large volume, high pressure water nozzles can be used to establish surface currents which are helpful in controlling floating oil. When these induced currents have components opposite to the ambient current, a turbulent rip zone is established where the opposing currents cancel. It is mainly by means of this zone that oil slicks may be influenced in a useful way. An empirical relationship for the distance between the impact point of the stream and the rip zone, as a function of nozzle output and natural current speed, has been determined and compared with a theoretical prediction based on a simplified model.

If the natural current is small, the rip zone's turbulence will be slight and it will be a barrier to approaching oil. If the natural current is large, the turbulence will be intense and the oil will be churned downward and pass under the zone. Techniques for the use of such large volume, high velocity water streams to control oil are described and their limitations are discussed.

This report was submitted in partial fulfillment of Project 15080 FVP, under the partial sponsorship of the Water Quality Office, Environmental Protection Agency.

CONTENTS

FIGURES

SECTION I

CONCLUSIONS

The effectiveness of fire streams in controlling oil spills is directly related to the amount of horizontal momentum that they put into the surface. The optimum input of horizontal momentum to the water is achieved when:

a) The largest available tip is used.
b) Solid streams are used.
c) The maximum pressure consistent with solid stream operation is used.
d) The monitor is horizontal or at a slightly depressed elevation.
e) The height of the monitor above the water is a minimum.

The fire stream establishes a fan-shaped current structure in the water. If this current structure has components directed opposite to the natural current, a turbulent rip zone will develop at its upstream edge. The distance from the impact point and width of the "front" covered by the rip zone increase as the horizontal momentum input to the water increases and as the natural current velocity decreases. In open water, the net flow in the rip zone is tangential to it and directed away from a horizontal axis drawn parallel to the fire stream. But, when confined in a channel so that the rip zone extends across the entire width of the channel, there is no net flow in the rip and it becomes a null current zone.

If the natural current is small, the turbulence of the rip zone is not intense and it will be a barrier to floating oil. Under these conditions the zone can be used to block or direct the flow of oil. In general, this will be accomplished by directing the fire stream in the direction of desired oil movement.

If the natural current is large, the turbulence of the rip zone will be intense, and it will not be a barrier to floating oil. Under these conditions, the fire stream may only be used to divert the oil usually by directed the stream at right angles to the direction of the natural current.

Since the fire stream must play on nearly the same spot for several minutes before its effects are fully developed, and it must continue to play on this spot if the effects are to be maintained, it will usually be necessary to secure the fire boats when using their fire streams to herd oil.

SECTION II

RECOMMENDATIONS

Additional tests are needed to:

1. Determine more exactly the limiting velocity between "small" and "large" natural currents.
2. Determine the depth of penetration of the fire-stream-induced current.
3. Establish more firmly the relationship between horizontal momentum output of the fire stream, natural current speed, and size of the induced current structure.
4. Perfect methods of deflection for large natural currents.
5. Perfect methods of entrainment.
6. Perfect methods of using fire streams to position boom arrays.

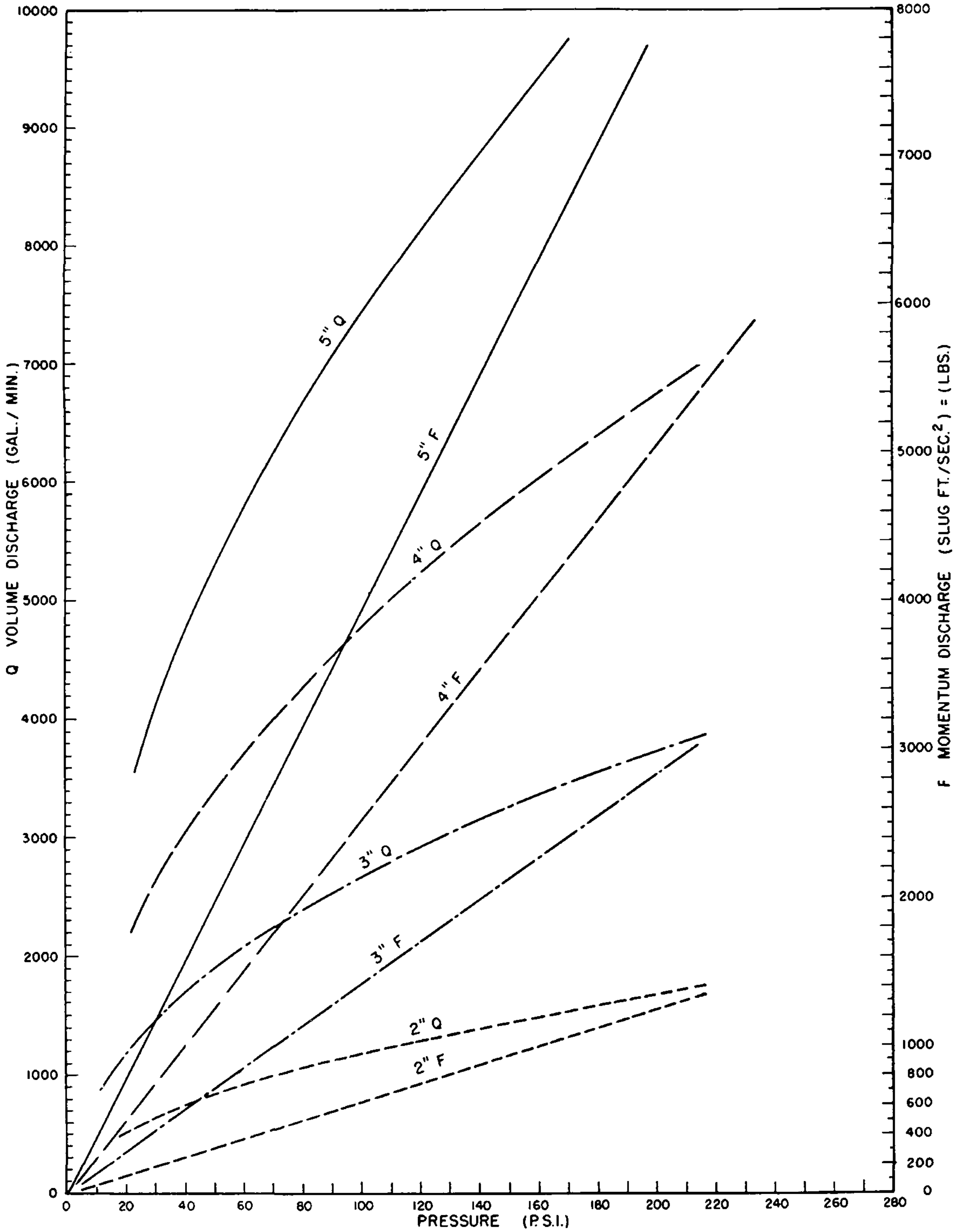
SECTION III

INTRODUCTION

This report deals with the use of water streams from fire hoses or monitors in controlling floating oil. It is also applicable, at least in part, to any device such as the Battelle Boom, which employs this method. However, fire streams and fireboats are stressed because in most cases only they are capable of generating the large output of momentum needed to materially affect significant amounts of floating oil, and are at the same time available for rapid deployment in many large harbors.

Until recently, the main use of fire streams at an oil spill was to "break up" the oil by playing the fire streams directly onto it. In cases of highly volatile petroleum products this still may be the best procedure for reasons of fire safety. But where explosion or fire is not a hazard, it has become vitally necessary to control and contain the oil so that environmental and property damage can be minimized and as much of the oil as possible can be recovered. This is exactly opposite to dispersal - the previous approach. Whereas dispersal required little in the way of special knowledge or techniques, control and containment are a far more difficult matter.

A number of experiments have been conducted with a view towards learning to apply the tremendous pumping capacity of fire boats to best advantage in controlling oil slicks. These have revealed that in certain situations fire streams can be quite effective if used properly, but if not used properly they may be totally ineffective or even counter-productive. The experiments are continuing. Frequently the results of one experiment will suggest other experiments and there still are many things to be tried and learned. However, we believe that enough has been discovered at this point to warrant the issuing of a preliminary report.



DISCHARGE (Q GAL / MIN) & MOMENTUM RATE (F SLUG FT./SEC.^{2}) = (LBS.)
VS. NOZZLE PRESSURE (P.S.I.) FOR SEVERAL NOZZLE DIAMETERS

FIGURE I

SECTION IV

FIRE STREAMS

For the purposes of controlling oil slicks, the useful output of a fire stream is its continuous discharge of momentum. This momentum discharge - the time rate of momentum output - is proportional to the product of the mass rate of water discharge multiplied by the discharge velocity; therefore, it is also proportional to the product of nozzle tip area and tip pressure (velocity head). It is, in fact, equal in magnitude, but opposite in direction, to the reaction force on the nozzle. Figure 1 shows the volume discharge, Q, and the momentum discharge, F, vs tip pressure for several different tip diameters.

Unfortunately, the entire momentum output of the tip is not usable. There are two reasons for this:

a) The fire stream usually enters the water at an angle. Therefore, it has a horizontal and a vertical component (Fig. 2); only the horizontal component is useful for the control of floating oil. The smaller the angle, A, the larger the horizontal component will be and the smaller the vertical component will be. The angle, A, is affected by the height of the tip above the water, the tip pressure, and angle that the tip makes with the horizontal. Decreasing the height of the tip, and increasing the pressure have the effect of reducing the angle A. For any particular height and pressure angle, A, will be the smallest when the tip is aimed horizontally, and A increases as the angle between the nozzle and the horizontal (whether elevation or depression) increases.

b) A portion of fire stream's momentum is lost to air resistance. Although the process by which this happens is not fully understood, it is known that, with the same pressure, air resistance increases with increasing tip size, and, with the same tip air resistance increases at an even faster rate with increasing pressure. (1) Also droplets are much more affected by air resistance than solid streams, and the smaller the droplets the more they are affected. Thus, nozzles which tend to break up the fire stream into fog or fine spray are generally ineffective. By the same token, solid streams should be operated at pressures well below those at which coning occurs.

Of course, the longer the fire stream the greater the effects of air resistance. Thus, while the smallest angle of entry, A, is achieved when the nozzle is aimed horizontally, a slight downward angle of aim would shorten the fire stream and the increase of momentum loss due to increased angle of entry would tend to be offset by the decreased loss due to the shorter fire stream. On the other hand, an upward angle of aim increases the fire stream length and the air resistance loss as well as increasing

COMPONENTS OF FIRE STREAM MOMENTUM DISCHARGE
AT THE WATER SURFACE

FIGURE 2

the angle of entry. Thus, depressing the tip from horizontal by several degrees will have little effect, but elevation from the horizontal produces rapid deterioration. For example: Nozzle elevation of -5° produced effects that were virtually indistinguishable from 0°, but +10° elevation produced a much truncated pattern, and at -20° elevation the fire stream had a negligible effect on the water movement.

FIRE STREAM INDUCED PATTERNS FOR VARIOUS ANGLES, θ, OF ORIENTATION BETWEEN THE FIRE STREAM AND THE NATURAL CURRENT.

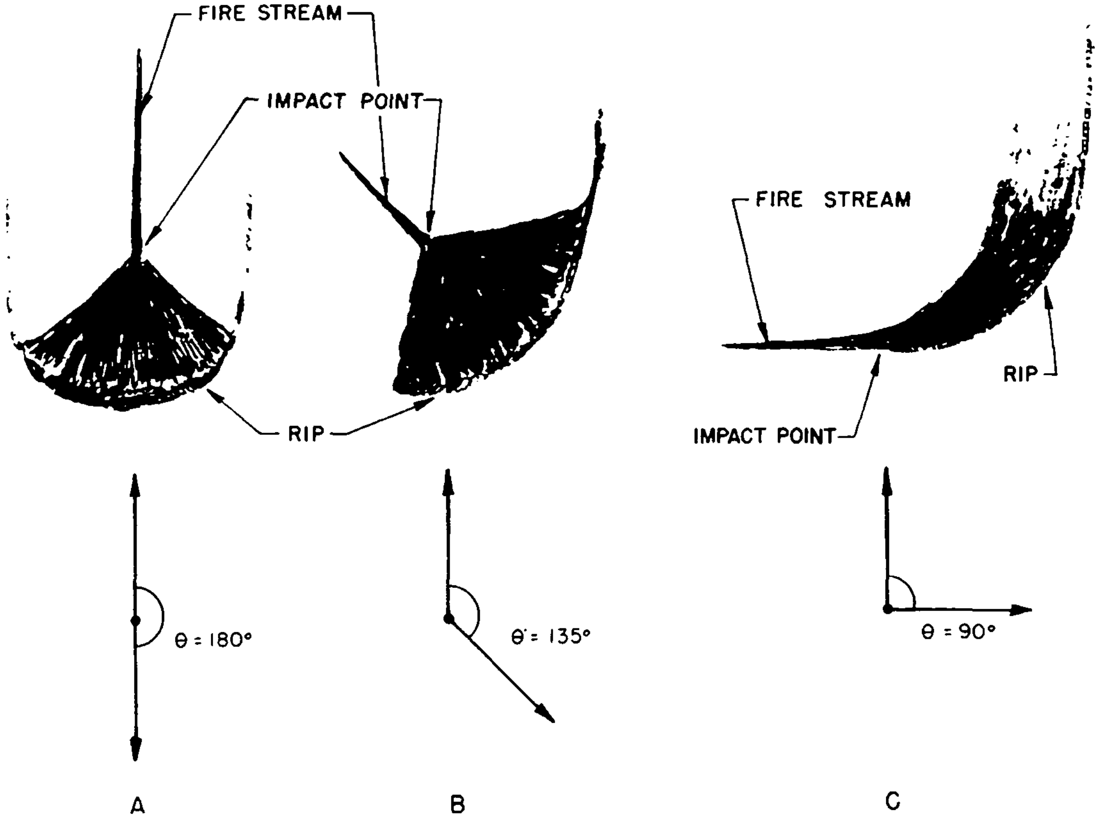


FIGURE 3

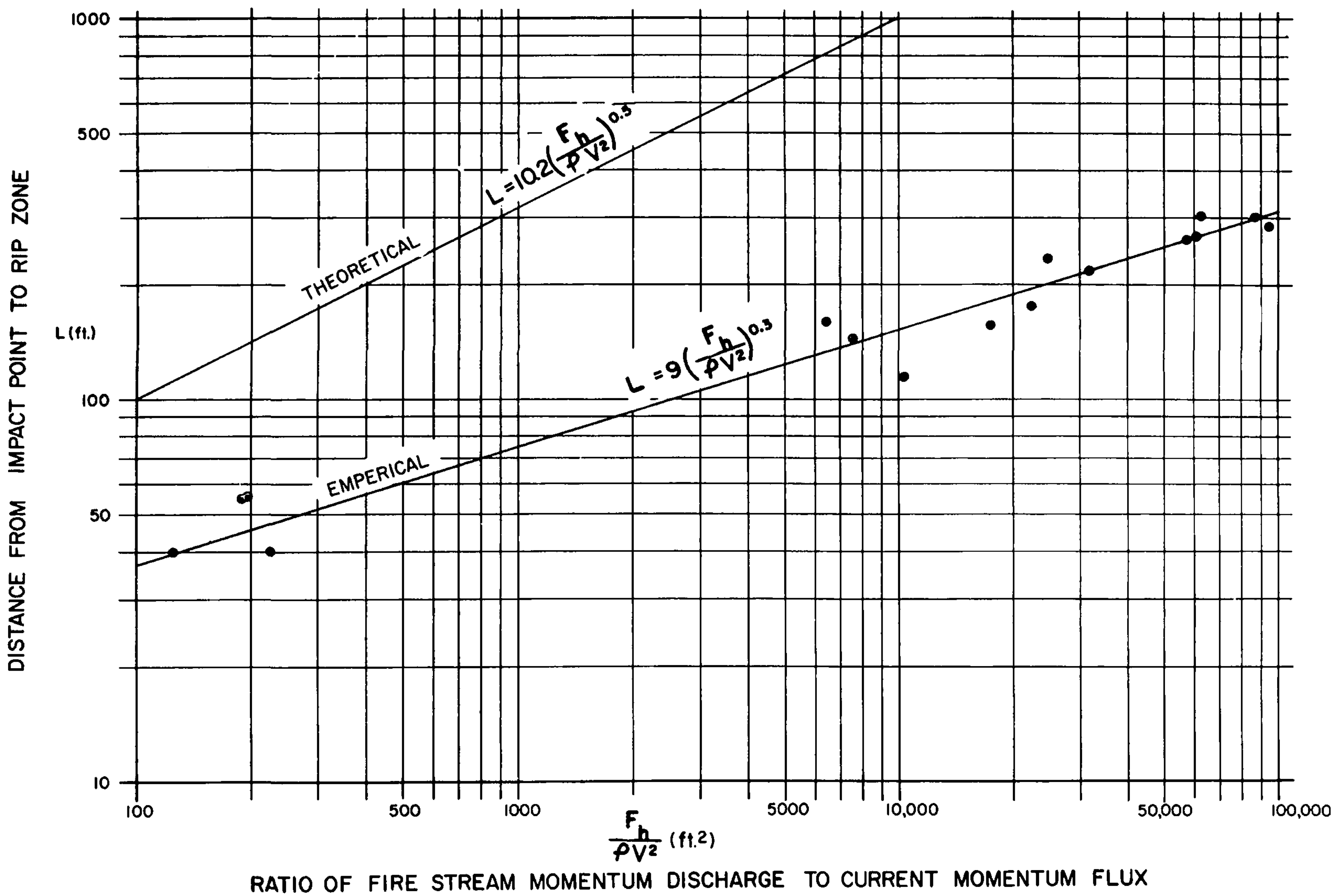
THE RIP IS THE TURBULENT ZONE IN WHICH OPPOSING COMPONENTS OF THE FIRE STREAM - INDUCED CURRENT AND THE NATURAL CURRENT CANCEL. IN A NARROW CHANNEL THE RIP BECOMES A NULL-CURRENT ZONE.

SECTION V
FIRE STREAM EFFECTS

When a fire stream plunges into a body of water, it establishes a fan-shaped pattern of turbulent, aerated water with velocity components in the general direction of the fire stream. The shape of the pattern depends on the angle of the fire stream with respect to the natural current (See Figure 3). Its size for a particular angle depends on the stream, and on the magnitude of the natural current. Velocities in the pattern, of course, vary, depending on where in the pattern they are measured.

When the fire-stream-induced current has components directed opposite to the natural current, a rip zone will be established in the region where these opposing currents cancel each other out. This zone determines the up-stream boundary of the pattern. The rip zone is not a stable region; it is turbulent and it meanders. However, it is by means of this rip zone that floating oil may be affected in a useful way. In open water, the net flow in the rip zone is tangential to it and directed away from a horizontal axis drawn longitudinally through the fire stream. But, when the fire-stream-induced current has components directed opposite to the natural current, a rip zone will be established in the region where these opposing currents cancel each other out. This zone determines the up-stream boundary of the pattern. The rip zone is not a stable region; it is turbulent and it meanders. However, it is by means of this rip zone that floating oil may be affected in a useful way. In open water the net flow in the rip zone is tangential to it and directed away from a horizontal axis drawn longitudinally through the fire stream. But, when the fire-stream-induced current is confined in a narrow channel so that the rip zone extends across the full width of the channel, there is no net flow in the rip and it becomes a null-current zone.

The distance of the rip or null-current zone from the impact point depends on the horizontal momentum flux of the fire stream at the impact point and on the speed of the natural current. For the case of fire streams directly opposed to the natural current two attempts have been made to determine this functional relationship. The first is based on an empirical analysis of test results; the second is based on a theoretical analysis (presented in detail in the Appendix) of a somewhat simplified model. Both results are shown in Figure 4, which is a plot to logarithmic scales of the distance, L, between the impact point and the null-current zone or rip zone vs. the horizontal component of fire-stream momentum discharge, F_h, divided by the momentum flux per unit area, ρV^2 (where ρ is the water density, and V is the velocity of the natural current through a vertical plane perpendicular to F_h.



DISTANCE FROM IMPACT POINT TO RIP ZONE
L (ft.)
1000
500
100
50
10
100
500
1000
5000
10,000
50,000
100,000
THEORETICAL
$L = 10.2\left(\frac{F_h}{\rho V^2}\right)^{0.5}$
EMPERICAL
$L = 9\left(\frac{F_h}{\rho V^2}\right)^{0.3}$
$\frac{F_h}{\rho V^2}$ (ft.2)
RATIO OF FIRE STREAM MOMENTUM DISCHARGE TO CURRENT MOMENTUM FLUX

FIGURE 4

The theoretical result,

$$L = 10.2(F_h/\rho V^2)^{0.5}$$

was determined from the model analysis. The corresponding line was then drawn from this equation. The empirical result,

$$L = 9(F_h/\rho V^2)^{0.3}$$

was found by first plotting the data points on Figure 4, drawing a best fit line through them, determining the corresponding equation. The discrepancy between the two results in due almost entirely to the differing exponents (0.3 and 0.5) with the difference due to the coefficients (9 and 10.2) being barely significant. It should be pointed out that

$$L = 10.2(F_h/\rho V^2)^{0.3}$$

is dimensionally consistent (as it would have to be from the way it was determined), while

$$L = 9(F_h/\rho V^2)^{0.3}$$

is not. However, the former does not correspond to any observed results. This divergence between theory and experimental results is discussed in the Appendix and deserves further investigation. In a general way, the two results are in agreement with each other and with expectation. Since F_h is porportional to tip area and tip pressure, while ρV^2 increases with increasing natural current, both results predict that larger distances between the impact point and the rip zone are associated with larger tip areas and higher tip pressures, and with lower natural currents. Smaller distances are brought about by the reverse situation.

It is possible to express either result by a series of curves of L vs. F_h for various current speeds. This has been done in Figure 5 for the empirical relationship. If the current speed is known, Figures 1 and 5 may be used to estimate L for various tip sizes and tip pressures. This may be done as follows:

(a) Find the momentum discharge, F, corresponding to the tip diameter and tip pressure from Figure 1.

(b) Take 90% of F as an approximation of F_h. (It is assumed that the monitor elevation is nearly horizontal, and its height above the water is not more than 20 feet, and tip pressure is greater than 25 pounds. If these conditions are not met, a smaller percentage of F should be used.

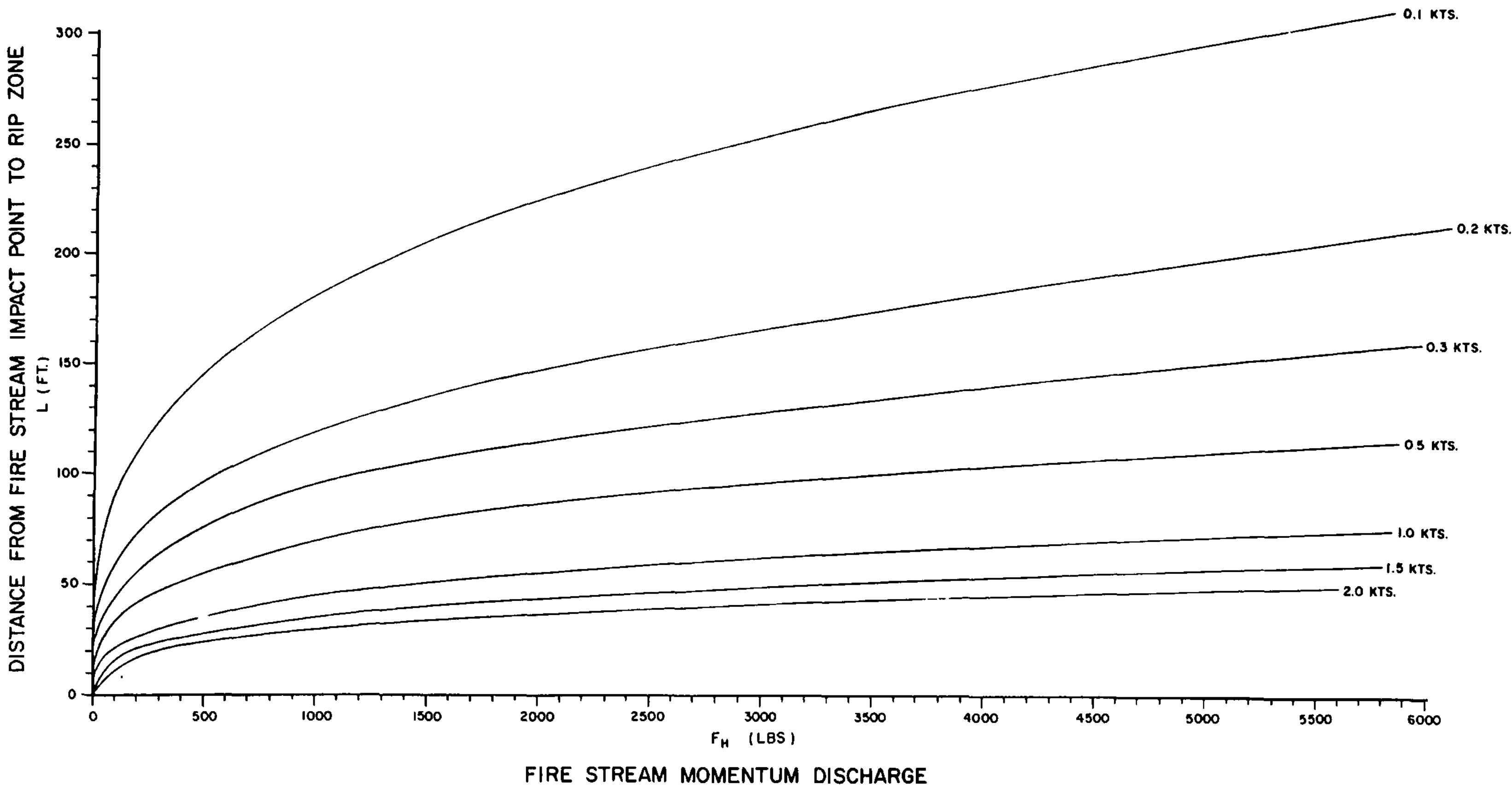

DISTANCE FROM FIRE STREAM IMPACT POINT TO RIP ZONE
L (FT.)
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
F_H (LBS)
FIRE STREAM MOMENTUM DISCHARGE
0.1 KTS.
0.2 KTS.
0.3 KTS.
0.5 KTS.
1.0 KTS.
1.5 KTS.
2.0 KTS.

FIGURE 5

(c) Find this value on the horizontal, F_h, axis of Figure 5; then read upward to the appropriate current velocity curve.

(d) The distance between the impact point and the null-current zone will be the corresponding value on the vertical, L, scale of Figure 5.

Though the relationships depicted in Figures 4 and 5 must, at this point, be considered tentative and subject to modification as more data are collected, the values of L obtained in this way should give reasonable approximations provided the tip pressure and current speed are accurately known. However, weak currents are difficult to measure and are usually highly erratic. Significant deviations from the above relationships will probably be due to imperfect knowledge of current speed.

The length of the rip zone (approximately the width of the fan-shaped pattern at its furthest from the impact point) is probably also related to $F_h/\rho V^2$, but because end points of the rip zone are difficult to see when the natural current is small, not enough observations have been made to establish this relationship. However, a number of observations of the angle subtended by the edges of the fan, at several different natural current speeds, have all yielded values between 80 and 90 degrees. If this is borne out by future work (in particular if the angle remains constant with distance from the impact point, which it seems to do, and if it is not also dependent upon the natural current speed) the relationship between the length of the rip zone and its distance from the impact point is a simple geometric one, and the dependence of the length of the rip zone upon the fire stream's momentum discharge and the natural current's momentum flux would follow from it.

For "small" natural currents (less than 1/2 knot) the rip zone is well separated from the fan-shaped aerated water near the impact point. It is a region of low turbulence which will divert or collect oil and other flotsam. For "large" natural currents, (greater than 1 knot), the rip zone is coincident with the edge of the aerated water. It is a region of high turbulence, and floating oil has been observed to go under or penetrate it. It is expected that with further experimentation the velocity range between "small" and "large" natural currents can be narrowed somewhat.

SECTION VI

CONTROL OF FLOATING OIL

The foregoing discussion of fire streams and their effects on the water surface shall form the basis for the tactics to be developed for using fire streams to control floating oil. However, it would be futile to try to anticipate every possible situation and develop cookbook methods for handling them. Rather, we shall suggest a number of possible uses of fire streams, and describe methods for their implementation. It will be left to the commanders on the scene to adapt these to specific situations. It should be stressed that no tactic should be followed blindly. The person in charge should frequently and carefully observe the results of the procedure being employed to be sure that the desired effect is being achieved. Often it will be found that the initial evaluation of a situation was in error, or that the conditions (e.g., current, wind) have changed. The required changes in tactics may be minor, such as re-aiming the monitor, or drastic, such as re-positioning the fire boat and/or boom array. Bear in mind that control and clean-up of any fairly large oil spill is likely to be a project of at least several days' duration. In sheltered areas along the edges of the main channels, in peripheral channels, and in parts of large shallow embayments such as New York City's Jamaica Bay, there are places where currents are insignificant. But in most places currents are a factor which will have to be considered. Since the currents are mainly tidal, it will be necessary, in such places, to plan on rather drastic changes approximately every six to twelve hours, depending on whether the tides are semi-diurnal or diurnal. All this may seem obvious, but it has been observed that one of the main causes of wasted effort at oil spills is inattentiveness. The other major cause is lack of knowledge, which is gradually being remedied.

In most cases, fire streams will be used in conjunction with and in fairly close proximity to (i.e., within several hundred feet of) a boom array or bulkhead. Unless the current is virtually nil and the extent of the oil patch small, operating a fire stream in open water, far from an enclosure or barrier of some sort can, at best, result in an insignificant diversion, and at worst, can cause a greater dispersion or emulsification of the oil.

Also, it should be stressed that the fire stream should not be allowed to play directly on the oil, but rather at a point far enough away so that the stream does not "break up" the oil. For large caliber streams and low natural currents this can be from 100 to 200 feet. Remember the movement or blocking of the oil is accomplished by the null-current zone and the flow patterns set up in the water rather than by the fire stream itself. If the fire stream is allowed to play directly on the floating oil, the oil will be churned up, emulsified, and carried away by the natural current rather than contained.

A constantly shifting fire stream has little opportunity to develop a current structure. To fully develop its current pattern, the fire stream must play on nearly the same spot for several minutes, and it must continue to play on this spot to maintain the pattern. If the natural current is very small the angle of train can be varied continuously back and forth through a small arc, but this should be thought of as a broadening of the impact point. Tests have shown that, while it is possible for most fire boats having twin screws to maintain, for a few minutes, any heading with respect to natural currents of a few knots in combination with any angle of train of the bow monitor operated at pressures up to 150 psi, it is generally impossible to do this for an indefinite period. And to control oil effectively, the fire boat generally must maintain position as well as orientation. For these reasons it will be necessary, in most cases, to secure the fire boat when using the fire streams to control oil. Furthermore, experience has proved that a large percentage of the spills will probably occur near a bulkhead or dock to which the fire boat can be moored.

As with other methods of oil control, fire streams are far, far more effective in the presence of low natural currents than they are when the natural current is high. Fortunately, in harbors the majority of spills occur near shore, where the currents are often small, even though the current in the main stream may be quite large. In cases of collision, the ships involved should be moved to shore if possible as a first step. For these reasons, and also because the oil film will be thicker and less dispersed near the source, the major effort should be expended at or near the site of the spill. Only after everything possible is being done at the source, should any remaining capability be expended in more distant areas.

SECTION VII

TACTICS FOR SMALL NATURAL CURRENTS

In relatively confined channels, when the natural current is less than 1/2 knot, fire streams may be effectively used to set up a dynamic barrier (the null-current zone) to stop the progress of the oil. For example: they may be used to seal off the mouth of a slip or basin to prevent oil inside from getting out or oil outside from getting in. At 100 psi nozzle pressure a 3-inch tip was found to effectively cover a basin 200 feet wide, and a 5-inch tip was able to cover a 300-foot wide basin. These effective fronts can be augmented if necessary, by using additional monitors to create adjacent null-current zones.

The null-current zone is similar to a boom in many ways, and it can be used as a boom in cases where the fire boat can be maneuvered into a suitable position. Its major disadvantage in this respect is that the fire boat could not then be used for other activities. However, it has two important advantages: the null-current zone can be easily penetrated by small boats, while a boom cannot. And a fire stream can be activated or adjusted much more quickly and easily than a boom can be deployed or moved. Where speed is essential, fire streams may be used initially to contain the oil until boom can be deployed, whereupon the fire boat would be free to perform another function. Whether the boom should be deployed between the oil and the fire boat, or the fire boat should be included in the enclosed area, will depend on the nature of the other function.

Fire streams may be used to move oil from under piers or between pilings where it is not readily accessible for recovery. In most cases this may be done by directing the fire stream so as to establish a flow under the pier or through the pilings that will push the oil out. Where this cannot be done, it may be possible to draw the oil out by entrainment. In this process, the fire stream is used to establish a current across the mouth of the area to be cleared, which in turn, will cause an outward flow of surface water from the area. Figure 6 shows an example how entrainment might be used. The arrows indicate the direction of flow. Though this method has worked, we have not yet made sufficient tests to optimize the techniques, and it should be used with caution. In instances where a fire boat could not be well-positioned for flushing out hidden oil, streams with hoses or pipe extensions such as under pier or cellar pipes have been used with considerable success. It is worthy of mention that, at high tide, the water surface under many piers may be completely enclosed by the piers' super structure, and the trapped oil cannot be driven out until the water level lowers.

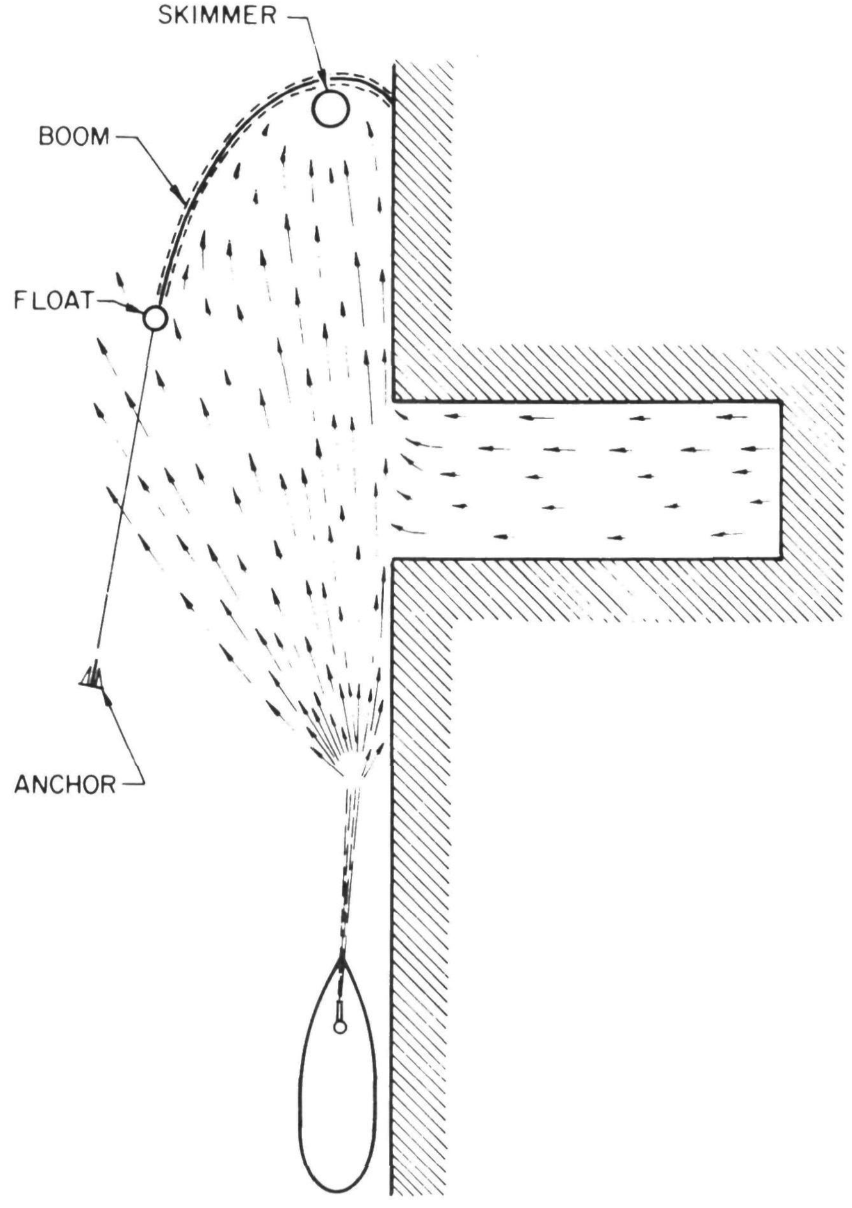


FIGURE 6
DRAWING OIL OUT OF AN EMBAYMENT BY ENTRAINMENT

The efficiency of an oil pick-up device can be greatly increased if fire streams are used to herd the oil towards the pick-up point. A pick-up point will be in a semi-enclosed area (e.g., a corner where two bulkheads meet, the apex of a boom array, the juncture between a boom and a bulkhead, etc.). If the area is small, hose and hand-held nozzles will be most effective. The objective is to maintain a continuous layer of oil on the water surface, having the maximum possible thickness, in the vicinity of the pick-up device. If there is no natural current, the oil will continue to move towards the pick-up point until a balance is reached between the hydraulic head in the oil layer and the pressure exerted on the edge of the oil by the fire-stream-induced current. The current should be very slight at the oil edge to avoid churning the oil. As oil is removed by the pick-up device, the edge of the oil will recede towards the pick-up point. If there is a slight current opposing the fire-stream-induced-current, the limit of effectiveness of the fire stream will be marked by a null-current zone. In this case, the edge of the oil will not recede towards the pick-up point. Rather, the oil will tend to collect along the null-current zone, and it will be necessary to advance the impact point of the fire stream. This can be done by elevating the tip, but a price is paid in reduced efficiency. The better way is to increase the tip pressure or to advance the nozzle. Think in terms of advancing the null-current zone (which can be considered to be one of the boundaries of the pick-up area) so that the pick-up area is completely covered by the oil layer. If the natural current is towards the pick-up point fire streams may still be useful in directing the oil.

SECTION VIII

TACTICS FOR LARGE NATURAL CURRENTS

When the natural current is in excess of one knot, the null-current zone ceases to be a barrier to floating oil. It is too turbulent, and the oil mixes downward and is carried past it. In short, it is no longer possible to block the movement of the oil. However, tests have indicated that for currents up to about 2 knots, it may be possible to divert the oil; the method is similar to entrainment. The fire stream is directed perpendicular to the natural current, as in Figure 3C, rather than against it. Oil carried by the current to the fire-stream-induced pattern will be shunted to the end of the pattern. In this case emulsification of the oil is unavoidable, but there is less tendency for the droplets to be dragged downwards. Diversions of up to 70 ft. have been accomplished in this way. Note that the area between the fire boat and the impact point of the fire stream will still be open to the unimpeded flow of oil. However, other streams may be used to close this gap. The impact point of these auxiliary streams should be slightly upstream of the impact point of the main stream. Rail pipes could serve well to generate the auxiliary streams.

Some success in eliminating the gap and lengthening the deflection has been achieved by using nozzles held horizontally very close to the surface of the water so that the fire stream just skims the surface. So far this method has been effective only in the absence of waves. The objective is to concentrate as much high velocity momentum as possible right at the water surface for the full length of the fire stream. This is impossible when the wave height exceeds about half the diameter of the fire stream because the wave crests will interrupt the stream and the wave troughs will allow oil to pass under it. Also wave induced rocking of the boat will often cause the nozzle to dip below the surface thus periodically destroying the stream at its source. Attempts to overcome these difficulties by increasing the vertical spread of the stream and holding the tip higher have been unsuccessful because the moemntum output is excessively diluted by the reduced velocity and by the spreading of the stream itself.

Since the objective is clean-up of the oil, it will have to be diverted to a place where this can be done. For the present this means a semi-enclosed area where the currents are small. It may not be possible to accomplish the necessary diversion with one fire boat, but if the other boats are available, additional structures may be established so that the necessary diversion can be accomplished in a step-wise fashion. This diversion technique might also be used to protect an area, for example a marina, by forcing the oil to flow around rather than through it.

For currents greater than about 2 knots there is very little that can be done in the way of control by fire stream.

SECTION IX

USING FIRE STREAMS TO ADJUST BOOM CONFIGURATION

Fire streams can be used to modify the shape or position of a section of containment boom. This is particularly useful at times when it may be desirable or necessary to fasten only one end of the boom to a pier or wall. The technique is more likely to be useful in protecting an area rather than in corralling oil. The up-stream end of the boom is fastened to the pier or bulkhead, and the fire streams are used to push the boom outwards into the main stream, thus forming a protected embayment which can be entered from the open, down-stream end. A similar result can be achieved with a number of anchors. This is an alternative method which is more quickly and easily activated and which might, in some cases, be more effective.

Left to itself the boom will tend to line up with the natural current. With the fire stream in use, that portion of the boom towards which the fire stream is directed will "belly" outwards. Down-stream of the "belly", the remaining boom, if any, will trail in the natural current again. The extent of the "bellying" depends, of course, on the natural current speed, the rate of momentum input to the water at the impact point, the proximity of the impact point to the boom, the overall length of the boom, and the angle between the fire stream and the natural current. Using a 3-inch tip at 30 psi it was possible to hold 100 ft of boom out in a current of 0.2 knots; with 120 psi in a 1 knot current the boom was held out only 30 feet. Using a 5-inch tip at 120 psi, 70 feet of boom were held out in a 1-1/2 knot current. In each case the total length of boom was 200 ft.

Care must be taken to avoid "spilling" or twisting of the boom, and this imposes limits on the fire stream output and/or the proximity of the impact point to the boom. To achieve optimum displacement without causing the boom to spill or twist it is best to start with tip pressures moderate and/or the impact point at some distance from the boom, and then gradually increase the pressure while closing the distance. The impact point is generally advanced by increasing nozzle elevation, but, for reasons already discussed in the section on fire streams, elevation much above the horizontal is likely to be counterproductive.

There are two basic configurations: In the first, the fire boat is almost directly down-stream of the tied end of the boom; as, for example, when both are secured to a bulkhead which is parallel to the current. The fire stream is directed against the current and between the boom and bulkhead thus forcing the boom outwards. This method can be used to protect an exposed area such as a small marina. Because the fire stream and the current directly oppose each other along a line containing the moored end of the boom, this configuration is somewhat unstable, the boom having a tendency to fold back upon itself, unless the impact point is kept about 100 feet up-stream of the trailing end of the boom. In order to initiate boom movement, it may be necessary to use a small boat to open a space for the fire stream impact point between the boom and bulkhead. Although the fire stream can impact quite close to a wall without causing any damage, it should never play directly onto the wall. If the currents are strong (greater than one knot) some oil will go under any section of the boom making a large angle with the current.

In the second configuration the fire boat is abeam of the boom and directing its stream perpendicular to the current; as, for example, when the boom fastened to the end of a pier, and the fire boat is moored to the side of the pier closer to shore. Though it is not possible to achieve, under the same conditions, as much displacement as with the former method there are no instability problems. Also there is evidence that a boom supported by a fire stream in this way may be more effective than either boom or fire stream alone. Oil that penetrated the barrier near the moored end has been observed to skirt the inner edge of the boom.

It is frequently impossible to avoid a gap where the boom end is fastened to a wall. This is particularly true where allowance must be made for the rise and fall of the tide. When no other means are available, this gap can be sealed quite effectively by means of fire streams. Since the gap will usually be only several feet wide, small caliber streams will in most cases be quite adequate.

SECTION X

ANCHORING

In a previous section we explained the need for securing a fire boat in order to use its monitors effectively. There are other activities (e.g., boom deployment and retrieval) which are much more quickly, safely and easily performed from a moored boat than from one that is hove-to. Yet, in many places where such activities might be required, there are no mooring facilities. For these reasons an effective anchoring system that can be rapidly and safely deployed will, at times, be a very valuable aid.

Almost all boats carry anchors, but, on many fire boats and other type boats of equivalent size, the anchor is a stockless or "patented" type weighing about 1/4 ton. Because of the need for bow fenders, the anchor is not kept in a hawspipe from which it can be readily dropped, and it must be put over the rail. The equipment is so cumbersome that the usefulness of the anchor in an emergency situation is virtually nil. Yet, it is possible to put together an anchoring system which is at least as effective in terms of holding strength, but which can be handled easily, safely, and quickly by only two men. Its components and their specifications are listed below:

a) Anchor - 85 lb Danforth (lightweight) standard. Holding strength 2,700 lbs in soft mud; 19,000 lbs in hard sand. (For comparison: the holding strength of the 1/4 ton stockless is 1,800 to 7,200 lbs depending on the bottom; the reaction force on a 5-inch tip operating at 100 psi is 3,926 lbs, but surges in anchor line tension up to 1000 lbs greater have been measured.

b) Chain (50 ft) - 1/2", hot galvanized, proof coil. Working load 4,250 lbs; proof load 8,500 lbs; min. break test 17,000 lbs.

c) Line (use a length equal to seven times the maximum anchoring depth)- nylon, 1-1/4", 3 strand, hard lay. Working load 4125 lbs; tensile strength 37,000 lbs.

Whether or not anchoring is possible in a particular situation will depend on the type of bottom, the anchoring gear available, and the current and wind speeds. But once anchored in a steady current, and with the fire stream operating at a constant pressure and angle of train, an equilibrium of forces will develop that will hold the boat steady. However, any change in the natural current, or the fire stream will force the system to seek a new equilibrium, which means that the fire boat will move. If it is possible to set up in such a way that the anchor line, current, and fire stream all have the same line of action, these motions will be kept to a minimum.

SECTION XI

ACKNOWLEDGMENTS

The practical use of fire streams at actual spills and at numerous test exercises provided the basic information for this report. The Officers and Members of the Marine Division of the NYFD and the personnel of Alpine Geophysical Associates were the principal project participants.

The guidance of Mr. Howard Lamp'l, EPA Project Officer, and the cooperation of the City of New York and the US Navy in providing the test basin at Wallabout Creek, Brooklyn, New York, is gratefully acknowledged.

SECTION XII

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SECTION XIII

GLOSSARY

Ambient Current - any naturally occuring water current (eg. tidal, wind driven, river flow).

Boom - A floating barrier used to contain oil on the water surface, or to direct its movement.

Coning - The break-up of a fire stream into tiny droplets and its spreading into a conical shape as a result of excessive pressure.

Fire Stream - A stream of water produced by fire fighting apparatus.

Induced Current - An artificially produced flow of water, such as that caused by a boat's propeller or by a fire stream directed into a body of water.

Monitor - A large nozzle with associated piping and controls attached to the deck of a fire boat for producing large volume fire streams.

Natural Current - Ambient current.

Null Current Zone - A rip zone in which there is no net flow of water.

Rip Zone - A turbulent surface region where two oppresing currents have equal strength. Usually there is no net flow through the rip zone, though there is often flow under or around it.

Tip - The nozzle of a monitor or fire boat.

SECTION XIV

APPENDIX

The data on countercurrents generated by directing a stream of water from a fire nozzle into the current shown in Figure 4 is here augmented with the development of a simple theory which explains the main features of the resulting empirical relationship. Some of the simplifying assumptions necessary to this theory, however, have resulted in a incorrect prediction of the exponent, even though the form of the result agrees with the empirical result.

This theory is an attempt to predict the location of the "null point", or point where the fire stream jet current exactly counters the natural river or tidal current, when the fire stream is directed into the current. It is developed from an analysis of a horizontal jet at the water surface, and is based on the following conceptual model:

The fire stream hitting the water, generally at some downward angle, is here considered to be a horizontal axisymmetric jet at the water surface. The natural current in the water is assumed zero for the moment. The initial diameter and velocity of the jet are chosen such that both the water flow rate and the momentum flux through the lower half of the axisymmetric jet match the flow and horizontal momentum flux from the fire nozzle on the boat. The equation describing the velocity distribution as a function of distance from the initial jet is used to calculate the distance from the jet (or impact point of the fire stream) to the point where the centerline velocity has decayed to the value of the opposing natural current. Finally, it is assumed that the natural current and the jet-induced current can be superposed, so that the above point represents the null point.

The details are as follows:

The fire nozzle discharge velocity, U_n, can be calculated from the pressure, P_o, behind the nozzle; if the pipe diameter where the pressure is measured is at least twice the nozzle diameter, the relationship simplifies to

$$U_n = (2\ P_o/\rho)^{1/2}$$

where ρ is the mass density of the water. The jet momentum flux of a horizontal nozzle is given by

$$F_h = A_n\rho\ \ U_n^2 = 2\ P_o\ A_n$$

where A_n is the cross-sectional area of the nozzle. For Nozzles aimed at an angle Θ from the horizontal, the horizontal momentum flux becomes

$$F_h = 2\ P_o\ A_n \text{ Cos } \theta$$

Considering now the half of the axisymmetric jet at the water surface, the diameter of this jet, d_j, in relation to the nozzle diameter, d_n, is given by $d_j = \sqrt{2}\, d_n$. This yields the same flow rate through the "half jet" at the nozzle velocity as is delivered by the fire nozzle. With the jet velocity, U_j, taken as the nozzle velocity, U_n, (for nearly horizontal nozzles), the momentum flux requirement is satisfied.

Away from the jet (at least, say, six diameters), the decay of the centerline velocity of the jet with distance is approximately described by

$$\frac{U(z)}{U_j} = 6.4\ (d_j/z)$$

where z is distance from the nozzle along the centerline of the jet.(2) Setting U(z) equal to the natural current, V; replacing d_j with $\sqrt{2}\, d_n$, and U_j with U_n, and z with the distance to the null point, L, gives

$$L = \frac{6.4\ U_j d_j}{V} = \frac{9.0\ U_n d_n}{V}$$

This can be converted to the form of the empirical equation

$$L = 9\ (F_h/\rho V^2)^{\ 0.3}$$

by noting that $F_h = \rho\, A_n\, U_n^2 = \rho V_\pi^2\ \frac{\pi}{2}\ d_n^2$;

thus

$$L = 10.2\ (F_h/\rho V^2)^{\ 1/2}$$

These equations are both plotted on Figure 4. While the forms of the variables agree, the exponents differ strongly and the coefficients differ slightly. Probably the most serious source of these differences lies in the use of the equation for a horizontal axisymmetric jet to develop the theory.

The equation developed in the appendix describes a jet wherein the lateral (e.g., downward) diffusion of momentum is controlled by the turbulence generated by the jet itself, while a fire stream striking the water at an angle of perhaps ten to thirty degrees generates intense turbulence and downward transport greatly in excess of that accounted for in the theory. This greatly increased downward momentum flux would have the effect of slowing the centerline velocity to the natural current speed much sooner, yielding much lower values of L.

There appears at the moment no tidy analytic way of accounting for this in theory. Further understanding can probably best be gained by a series of careful model studies. For rough predictive purposes, however, the empirical curve of Figure 4 appears adequate.

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16. Abstract

The substantial momentum output of large volume, high pressure water nozzles can be used to establish surface currents which are helpful in controlling floating oil. When these induced currents have components opposite to the ambient current, a turbulent rip zone is established where the opposing currents cancel. It is mainly by means of this zone that oil slicks may be influenced in a useful way. An empirical relationship for the distance between the impact point of the stream and the rip zone, as a function of nozzle output and natural current speed, has been determined and compared with a theoretical prediction based on a simplified model.

If the natural current is small, the rip zone's turbulence will be slight and it will be a barrier to approaching oil. If the natural current is large, the turbulence will be intense and the oil will be churned downward and pass under the zone. Techniques for the use of such large volume, high velocity water streams to control oil are described and their limitations are discussed.

This report was submitted in partial fulfillment of Project 15080 FVP, under the partial sponsorship of the Water Quality Office, Environmental Protection Agency.

17a. Descriptors

*Oil, *turbulence, *Eddies, *Hydraulics, *Jet, *Piers, *Velocity, *turbulence, *pressure *Anchors, *Basins, *Boats, *Currents (water), *Docks, *Oil Spills, *Nozzles, *Discharge, *Training, *Harbors, *Inland Waterways, *Entrainment, Momentum Transfer, Emulsions,

17b. Identifiers

*Surface Currents, *Monitor Streams, *Hose Streams, *Fire Departments, *Booming, *Herding, *Rip Zone, *Null Current Zone.

17c. COWRR Field & Group

18. Availability

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